ADVANCED POWER FLOW TOPOLOGY CONTROLS FOR THE GRID

UPDATED: OCTOBER 28, 2015

PROJECT TITLE: Transmission Topology Control for Infrastructure Resilience to the Integration of Renewable Generation

PROGRAM: GENI

AWARD: $2,361,591

PROJECT TEAM: *Boston University (Lead)*; Newton Energy Group; Northeastern University; AIMMS; PJM Interconnection; Polaris Systems Optimization; The Brattle Group; Tufts University

PROJECT TERM: April 2013 – March 2016

TECHNICAL CHALLENGE

The primary objectives of electric market and grid operators are to ensure reliable operations and minimize the cost of providing electricity by purchasing and delivering this energy source from the lowest-cost generators to customers. However, these generators are not always ideally located to service customer needs. As a result, utilities must purchase electricity from higher-cost generators and/or curtail renewable generation, to levels at which transmission lines do not exceed their thermal limits, causing reliability problems and network congestion. Purchasing (or dispatching) more expensive electricity sources due to transmission congestion leads to multi-billion dollar congestion costs annually in the United States. Active management of transmission and distribution is needed to enable more low-cost renewable generation sources to penetrate the electric market, improve grid resiliency and reliability, and reduce electricity costs for end users.

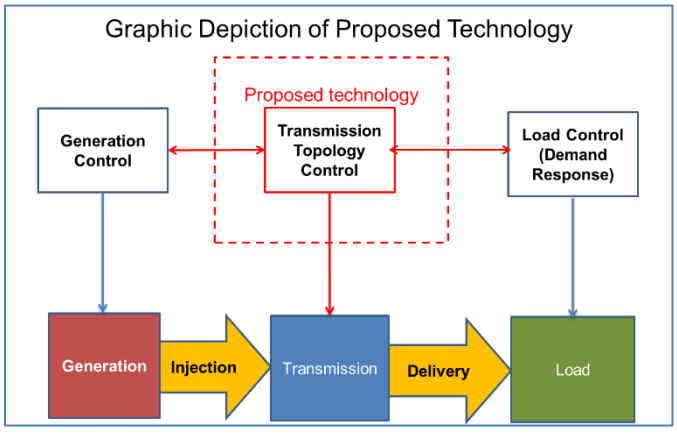
TECHNICAL OPPORTUNITY

Today, flows in the electric grid are typically managed by adjusting the power drawn from different generators (i.e. generation dispatch) and/or modulating electricity demand (i.e. demand response), assuming for the most part an uncontrollable transmission system. Transmission network changes at present are created by switching specific lines in and out of service. Network flexibility is usually not exploited in optimizing electricity supplies and demands because the procedures to determine good configurations are complex and the analysis and implementation processes are slow. Advances in applied mathematics have created new methods for identifying solutions to the network configuration problems in the form of fast optimization algorithms that can be implemented with modern computational capabilities.

INNOVATION DEMONSTRATION

Boston University's (BU) topology control technology is designed to help grid operators actively manage power flows and integrate renewables by switching entire power lines in and out of service in coordination with traditional management of generators and demand. The topology control technology identifies transmission lines to be switched to mitigate network congestion and improve system reliability.

Figure 1: Demonstrates the transmission of Boston University's power flow technology



Identifying beneficial reconfigurations in real time is difficult due to the complexity of even a moderate-sized utility grid. The BU research team has made breakthroughs by drawing on their previous academic research in fast, computationally tractable algorithms. The team's topology control technology uses fast optimization algorithms taking advantage of sensitivity information from the system. Their algorithms identify incremental network topology modifications on a time scale that enables their implementation to improve reliability and decrease congestion costs.

BU researchers worked on detailed, operational network models demonstrating the ability to generate solutions on an operationally relevant time scale (~5 minutes), the potential to save up to 50% in congestion costs in some systems under average historical grid conditions, the ability to reduce renewable curtailments by 40% in a high-renewables scenario, and the capability to relieve significant overloads even under peak demand conditions.

PATHWAY TO ECONOMIC IMPACT

The BU team has received additional funding from the Massachusetts Clean Energy Commission, and is working to market their topology control algorithms (TCA) technology through established consulting entities that have the knowledge and relevant personnel to be able to market the TCA systems.

The team is also working with industry stakeholders to integrate topology control into grid operations decision making, focusing first on improving established utility/International Organization for Standardization (ISO) business processes that do not require market rule modifications. Aside from market rules, the team will work with industry stakeholders on addressing hurdles to topology control, such as multi-party coordination and equipment protection. The team has formed a software company to develop the commercial decision support tool.

LONG-TERM IMPACTS

The BU team has demonstrated that large-scale topology control is tractable. There are many uses for this type of software (from intra-day dispatch to outage coordination to system planning). It remains to be seen what particular application generates traction first. Adoption of the topology control technology in some electric grid decision-making processes may require changes to the day-ahead and real-time electricity market rules and/or procedures, while other processes already deploy topology changes to a limited extent. Market use in these processes may occur first and proceed in parallel with developments in market rules and/or procedures.

PUBLICATIONS

The BU team has published scientific underpinnings of the technology extensively in the open literature. A list of publications is provided below:

P. A. Ruiz, J. Foster, A. M. Redkevich and M. C. Caramanis, "*Topology Control Algorithms (TCA): Economic and Corrective Applications*", 2012 FERC Conf. Improving Market Efficiency, Docket AD10-12-003, June 2012.

A. Rudkevich, "*A Nodal Capacity Market for Co-optimization of Generation and Transmission Expansion*", Proc. 50th Allerton Conference on Communications, Control and Computing, October 2012.

P. A. Ruiz, A. Rudkevich, M. C. Caramanis, E. Goldis, E. Ntakou and R. Philbrick, "*Reduced MIP formulation for transmission topology control*", Proc. 50th Allerton Conference on Communications, Control and Computing, October 2012.

M. Stanković and A. T. Sarić, "*Fast Assessment of Eigenvalue Sensitivities to Topology Changes and Injection Perturbations*", Proceedings of IEEE PowerTECH Conference, Session "Loads and Flows Modeling", Paper A5494AS, Grenoble, France, June 2013.

P. A. Ruiz, M. C. Caramanis, J. M. Foster, E. Goldis, X. Li, C. R. Philbrick, A. M. Rudkevich, R. D. Tabors, T. B. Tsuchida, "*Advances in Topology Control Algorithms (TCA)*", 2013 FERC Conf. Improving Market Efficiency, Docket AD10-12-004, June 2013.

P. A. Ruiz, M. C. Caramanis, E. Goldis, B. Keshavamurthy, X. Li, M. Patel, C. R. Philbrick, A. M. Rudkevich, R. D. Tabors, T. B. Tsuchida, "*Transmission topology control for system efficiency – Simulations on PJM Real Time Markets*," presented at 2013 IEEE PES General Meeting, Super Session on Transmission System Efficiency and Reliability Improvements, Vancouver, BC, July 2013

A. Rouhani and A. Abur, "*Distributed Implementation of an augmented state dynamic state estimator*", 2013 North American Power Symposium, September 2013.

A. Rouhani and A. Abur, "*Improving Performance of Dynamic State Estimators under Unknown Load Changes*", 2013 IEEE PES General Meeting, July 2013.

S. D. Đukić, A. T. Sarić and A. M. Stanković, "*Approximate Bisimulation-Based Reduction of Power System Dynamic Model with Application to Transient Stability Analysis*", North American Power Symposium (NAPS), Kansas State University, USA, September 22-24, 2013.

E. A. Goldis, X. Li, Michael C. Caramanis, Bhavana Keshavamurthy, Mahendra Patel, Aleksandr M. Rudkevich, A. Ruiz, P. "Applicability of Topology Control Algorithms (TCA) to a Real-Size Power System", 51st Allerton Conference on Communications, Control and Computing, October 2013.

E. A. Goldis, M. C. Caramanis, C. R. Philbrick, A. M. Rudkevich and P. A. Ruiz, "*Security-constrained MIP formulation of topology control using loss-adjusted shift factors*", 47th Hawaii Int. Conf. System Science, January 2014.

P. A. Ruiz, M. C. Caramanis, E. Goldis, B. Keshavamurthy, X. Li, C. R. Philbrick, A. M. Rudkevich, R. D. Tabors, T. B. Tsuchida "*Topology control algorithms (TCA) – Simulations in PJM with AC Modeling*," 2014 FERC Conf. Improving Market Efficiency, Docket AD10-12-005, June 2014.

A. M. Rudkevich, M. C. Caramanis, E. A. Goldis, X. Li, C. R. Philbrick, P. A. Ruiz, R. D. Tabors, and T. B. Tsuchida, "*Advanced Methods in Transmission Topology Control Optimization and their Applications*", 2nd International Symposium on Energy Challenges & Metrics, Aberdeen, Scotland, UK, August 19, 2014.

P. A. Ruiz, X. Li, T. B. Tsuchida, "*Transmission Topology Control - Curtailment Reduction through System Reconfiguration*", UVIG 2014 Fall Technical Workshop, October 2014.

P. A. Ruiz, M. C. Caramanis, E. Goldis, D. Hislop, B. Keshavamurthy, X. Li, D. Moscovitz, C. R. Philbrick, A. M. Rudkevich, R. D. Tabors, and T. B. Tsuchida, "*Topology Control Algorithms: Applications for Market Efficiency Improvements and Overload Relief*", 2014 IEEE PES General Meeting Super Session on Grid Operations, National Harbor, MD July 30, 2014.

J. Goldis, X. Li, M. Caramanis, A. Rudkevich and P. Ruiz presented, "*AC-Based Topology Control Algorithms (TCA) – A PJM Historical Data Case Study*" at HICSS 48 in Hawaii in January 2015.

P. A. Ruiz, M. C. Caramanis, E. Goldis, D. Hislop, B. Keshavamurthy, X. Li, D. Moscovitz, C. R. Philbrick, A. M. Rudkevich, R. D. Tabors, T. B. Tsuchida, "*Topology Control Algorithms (TCA) – Simulations in PJM Day Ahead Market and Outage Coordination*," 2015 FERC Conf. Improving Market Efficiency, Docket AD10-12-006, June 2015

A. M. Rudkevich, M. C. Caramanis, E. Goldis, X. Li, P. A. Ruiz, R. D. Tabors, "*Preserving Revenue Adequacy in FTR Markets with Changing Topology*," 2015 FERC Conf. Improving Market Efficiency, Docket AD10-12-006, June 2015

P. A. Ruiz, J. Chang, "*Transmission Topology Control – Applications to Outage Scheduling, Market Efficiency and Overload Relief*," presented at WIRES Summer Meeting, Boston, July 2015

A. M. Rudkevich, M. C. Caramanis, E. Goldis, X. Li, P. A Ruiz, R. D. Tabors, "*Financial Transmission Rights in Changing Power Networks*," at HICSS 49 in Hawaii in January 2016.